Controversy between Einstein and Bohr and two erroneous arguments used in supporting Copenhagen quantum mechanics

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Abstract

The support of Copenhagen quantum mechanics in the discussion concerning EPR experiments has been based fundamentally on two mistakes. First, quantum mechanics as well as hidden-variable theory give the same predictions; the statement of Belinfante from 1973 about the significant difference must be denoted as mistake. Secondly, the experimental violation of Bell's inequalities has been erroneously interpreted as excluding the hidden-variable alternative, while they have been based on assumption corresponding to classical physics. The EPR experiments cannot bring, therefore, any decision in the controversy between Einstein and Bohr. However, the view of Einstein is strongly supported by experimental results concerning the light transmission through three polarizers.

In the controversy that started by two papers [1, 2] in 1935 Einstein's view was refused by the then physical community. The main reason consisted in the fact that any alternative of hidden-variable theory was refused by von Neumann [3]. The situation changed when Bell [4] showed that the refusal was based on classical-physics assumption used by von Neumann. Bell argued that the hidden-variable alternative was fully admissible and derived also his famous inequalities. According to Bell these inequalities should have been fulfilled experimentally for the hidden-variable theory, but violated in the case of the quantum mechanics. However, they have been based on the assumption, the impact of which has not been sufficiently analyzed, as will be shown below.

Bell's results caused, however, that the original EPR Gedankenexperiment was somewhat modified to be experimentally feasible. And the coincidence polarization experiments started to be performed practically in 1971. Decisive importance was given to them by Belinfante [5] when he argued that the two competitive theoretical alternatives (quantum mechanics and hidden-variable theory) had to lead to mutually different predictions. However, that has not been true as it will be shown now.

Polarized light going through two polarizers fulfills Malus law

$$M(\alpha) = (1 - \varepsilon)\cos^2(\alpha) + \varepsilon \qquad (1)$$

where α is the mutual deviation of polarizer axes; expression (1) being valid for a pair of polarizers in one-sided as well as coincidence arrangements. The standard quantum mechanics deals, of course, with the so called ideal polarizers only, where $\varepsilon = 0$. For real polarizers it holds always $\varepsilon > 0$, for which the quantum mechanics has phenomenological explanation only.

In the hidden-variable alternative it is possible to write

$$M(\alpha) = \int_{-\pi/2}^{\pi/2} d\lambda \, p_1(\lambda) \, p_1(\alpha - \lambda) \qquad (2)$$

where λ is Bell's hidden parameter (deviation of photon polarization from the axis of the first polarizer). The function $p_1(\lambda)$ represents the distribution of transmission probability
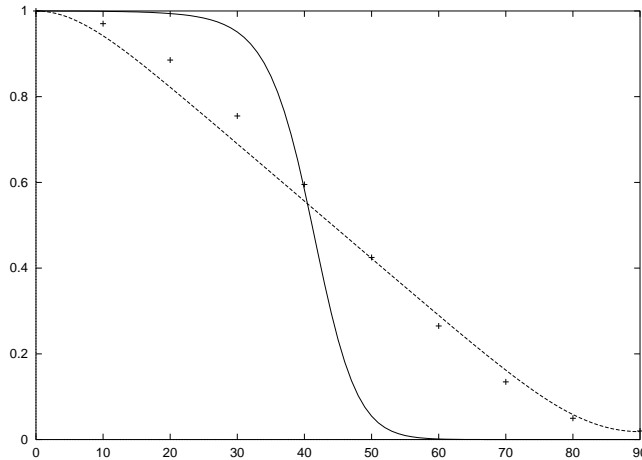
Figure 1: *Malus law and hidden variables; $p_1(\lambda)$ - full line, $M(\alpha)$ calculated according to Eq. (2) - dashed line; actual Malus law (see Eq. (1) - $\varepsilon = 0$) - individual points.*

of non-polarized light through one polarizer and must be found by fitting to obtain the Malus law according to Eq. (2), which is well defined and soluble problem. A simple approximate solution may be easily obtained if one puts, e.g.

$$ p_1(\lambda) \;=\; 1 - \frac{1 - \exp(-(a|\lambda|)^e)}{1 + c\exp(-(a|\lambda|)^e)}, \quad a = 1.95, \;\; e = 3.56, \;\; c = 500; $$

$p_1(\lambda)$ $(= p_1(-\lambda))$ is represented by full line and $M(\alpha)$ calculated for the given $p_1(\lambda)$ according to Eq. (2) by dashed line in Fig. 1; λ or α being shown on abscissa. The exact Malus law is represented by individual points; see also [6] [1]. A much better agreement with the Malus law may be obtained with a more flexibly parameterized function $p_1(\lambda)$.

To obtain the fundamentally different results Belinfante put quite arbitrarily

$$ p_1(\lambda) \;=\; \cos^2(\lambda), $$

which differs significantly from the curve obtained by fitting and shown in Fig.1; $\cos^2(\lambda)$ being represented e.g. by individual points in Fig. 1. It should not be any surprise when the EPR experiments (the first series having been finished in 1982, see [7]) have corresponded to the Malus law. And consequently, the polarization EPR experiments do not seem to be suitable for bringing any decision between the quantum mechanics and hidden-variable alternative.

However, an equally important problem has concerned the violation of Bell inequalities as they have been interpreted mistakenly. Until now nobody has analyzed the actual impact of the assumption involved in their derivation. Their actual impact was studied and shown for the first time in [8]. The whole problem has been then explained in a greater detail recently in the language of the Bell operator (see [6]).

The consequences will be summarized here very shortly only. The Bell operator is defined as

$$ B \;=\; a_1 b_1 + a_1 b_2 + a_2 b_1 - a_2 b_2 \tag{3} $$

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[1]The quoted paper was submitted also to Physical Review, but the publishing was refused by editorial board, which occurred also earlier in the case of other papers of ours containing some critical points towards the standard quantum mechanics.
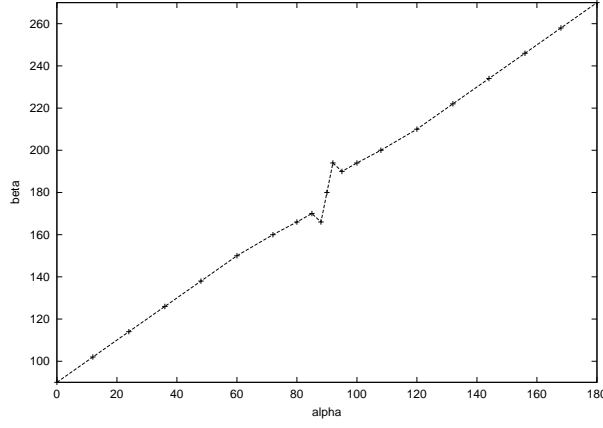
Figure 2: *The angle β corresponding to the minimum light transfer through three polarizers at a given α.*
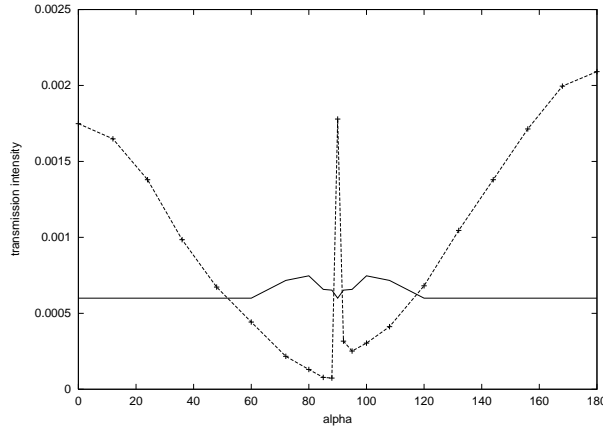

Figure 3: *The measured transfer intensity through three polarizers (points on dashed line) corresponding to different pairs of angles α and β (taken from Fig. 1). Full line: quantum-mechanical prediction (transmission through three ideal polarizers + additional phenomenological constant).*

where operators a_j and b_k represent measurements in individual polarizers (being in coincidence arrangement). It holds for expectation values of theses operators:

$$0 \leq |\langle a_j \rangle|, \ |\langle b_k \rangle| \leq 1.$$

The Bell operator may then have three different limit values in the dependence on the commutation relations between the operators a_j and b_k. It may hold (see [6])

$$\langle B \rangle \leq 2, \ 2\sqrt{2}, \ 2\sqrt{3}$$

where the individual limits correspond to: classical physics (all operators a_j and b_k commuting mutually), hidden-variable alternative, and Copenhagen quantum mechanics (no pair of commuting operators).

To obtain his inequalities Bell had to use an assumption the impact of which has not been sufficiently analyzed. It has been assumed for it to correspond to hidden-variable alternative, while in fact it has corresponded to classical physics (being practically

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equivalent to that used earlier by von Neumann). Therefore, it is only the classical-physics alternative that has been excluded by the results of EPR experiments. And the decision concerning the Einstein - Bohr controversy must be based on other experiments.

Such experiments were performed already more than 10 years ago when the transmission of light through three polarizers was measured (see [9]):

$$o----|---|^{\alpha}---|^{\beta}--->;$$

α and β being deviations of the second and third polarizers from the axis of the first polarizer. The main results may be seen in Figs. 2 and 3.

Individual points in Fig. 3 represent experimental transmission values in dependence on the angle α of the second polarizer, which have been determined in the following way: In individual cases the angle α was fixed and angle β of the third polarizer was established, so as the light transmission through the whole triple was minimum (corresponding β shown always in Fig. 2).

Full line in Fig. 3 represents then quantum-mechanical prediction for given angle pairs, having been estimated as the corresponding dependence for the triple of ideal polarizers with an added (unpredictable) constant. There is certainly a significant disagreement between quantum-mechanical prediction and experimental data; more details will be presented in [10].

And it is possible to summarize:
- there have been two mistakes in arguments, on which the support of Copenhagen quantum mechanics has been founded until now;
- in contradistinction to common opinion the results of polarization EPR experiments cannot bring any solution of the controversy between Einstein and Bohr, when only the classical alternative has been excluded by these results;
- the remaining controversy (hidden-variables vs. Copenhagen interpretation) may be decided e.g. on the basis of experiments with three polarizers; decisive preference given to the view of Einstein as quantum-mechanical prediction differs from experimental results.

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